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## Ergonomics, anthropometrics, and kinetic evaluation of gait: A case study

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### Abstract

This study aimed to develop appropriate changes in a pair of shoes in order to improve the gait of an individual selected for this case study. This analysis took into account ergonomic aspects, namely those relating to the individual's anthropometrics. Gait analysis was done with the adapted footwear both before and after intervention. A conventional X-ray was performed, which revealed a 29-mm left lower limb shortening and possible foot adduction. The anthropometric assessment confirmed a 27-mm asymmetry between the left knee and foot. Corrective changes were implemented in the left boot, with a 20-mm increase in the plantar aspect and approximately 30-mm in the calcaneus area. The pressure-mapping system WalkinSense was used for the kinetic gait analysis. Results showed some improvement in plantar pressure distribution after corrective changes in footwear. Peak pressure in the left foot decreased from 2.8kg/cm<sup>2</sup> to 1.6kg/cm<sup>2</sup>. The second peak also showed a marked decrease. The right foot presented with a reduction in peak plantar pressure from 2.7kg/cm<sup>2</sup> to 2.3kg/cm<sup>2</sup>. After identifying asymmetries, the associated pathologies and modifying the footwear, a kinetic analysis of gait before and after altering the footwear was undertaken, which showed improvements in the gait. According to the obtained results, it was possible to demonstrate that the initially proposed objectives were achieved, i.e., the changes in footwear resulted in an improvement of the analyzed individual.

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**Keywords:** Ergonomics; Anthropometry; Footwear alteration; Biomechanics; Gait analysis

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### 1. Introduction

This case study pertains to a young man with a congenital deficiency in the left leg characterized by the absence of the posterior tibial tendon. He has barely any gastrocnemius, thus preventing him from performing extension of the foot and leg flexion [1]. The subject underwent surgery, where doctors transferred the short peroneal tendon to

the Achilles tendon, and the extensor hallucis brevis to the posterior tibial, tenodeses hallux extensor with common extensor [2]. Currently, he presents an apparent adducted foot and his left leg is 3cm shorter. This asymmetry is practically all located between the knee and the foot. The leg appears slimmer from the knee to the foot, and the left foot is smaller and presents with muscular atrophy [3].

The field of ergonomics deals with the improvement of the conditions of humans, which includes designing systems and ensuring that they can be comfortable, safe and efficient [4]. The applied anthropometry, which can be considered as one of the sub-topics of ergonomics, contributes to ergonomics by identifying the body dimensions and through that a potential inadequate dimensioning and postures adoption, which may result in the prevention of a set of disorders, namely some related with the musculoskeletal system [5].

In its turn, applied biomechanics, which can be also considered a sub-topic of Ergonomics, studies the mechanics of biological systems, and the mechanical effects on body movement, size, shape, and structure (Whatkins, 1999 as cited in [6]). The main purpose of analyzing human movement is to understand the mechanical function of the musculoskeletal system while performing a motor task [6].

Altering footwear is commonly done to alter gait patterns, to improve comfort, and to treat a number of disorders of the lower limbs [7, 8, 9, 10]. Orthopedic devices are also used to enhance skeletal function [11].

In this study, it was necessary to understand the biomechanics of gait, the behavior of the lower limbs during the gait cycle, weight transfer, and distribution of plantar pressure. Gait analysis is specific to the study of human walking, and is used to evaluate, plan for, and treat individuals with conditions affecting their ability to walk [6].

The main objective of this study was to implement appropriate changes to a pair of shoes in order to improve the individual's gait while taking into account the ergonomic aspects, and to perform gait analysis both before and after altering the footwear.

## 2. Methodology

An X-Ray and an anthropometric assessment revealed a left lower limb shortening of approximately 30mm [3]. Thus, a kinetic gait assessment was essential.

To this end, we used the WalkinSense device, which can gather and process quantitative and qualitative information in real time, communicating with a computer, laptop or PDA via Bluetooth (25 meters reach) or USB cable. This device measures foot pressure and velocity more accurately than the currently accepted visual inspection or other less sophisticated devices. Thus, WalkinSense allows a quick and useful way to prescribe corrective orthotics.

Patients can use this device outside the clinical setting, since it is an easy-to-use, compact device. The battery operates with an adjustable strap for easy attachment to the ankle and allows users to continue with their daily activities with minimal disruption. The advantage of WalkinSense is that it measures foot pressure and speed much more accurately than the current visual inspection or less sophisticated devices with limited functionalities. This facilitates analysis of the lower limbs in a rapid manner, allowing for effective preventive treatments through corrective orthotics (e.g., custom insoles or shoes) that reduce the need for major interventions [12].

This system allows simultaneous monitoring of dynamic plantar pressure and activity on both legs, allowing for comparisons and detection of asymmetries in human gait. Moreover, it allows for both static and dynamic characterization of load distribution in the foot's contact surface.

### 2.1. Procedure

Several strips of adhesive Velcro were cut and fixed to the insoles where the pressure sensors were to be placed, with the same layout for both left and right foot (Figure 1). The choice of location for each sensor was determined by which features were important to evaluate. Given that the participant walks on the left heel, it was decided to place a sensor directly on the heels (sensor 5) and to eliminate the sensor on the internal lateral foot arch. Two sensors were positioned side by side on the first support (heel, sensors 6 and 7), sensor 8 was placed on the outer lateral area of the foot arch area, sensor 1 under the first metatarsal, sensor 3 under the metatarsal II, sensor 4 under the metatarsal III, IV and V (plantar foot area), and, finally, sensor 2 under the hallux (big toe). The metatarsal area was pertinent to this study since the participant presented with almost no movement in the toes.



Fig.1. Insoles with the pressure sensors placed and devices.



Fig.2. Sensor placement as viewed on the software.

The insoles were placed into the boots and the correct position of all sensors confirmed. The participant was asked to put on the boots, taking care to place the pressure sensors' USB plug facing the front. After adjusting and lacing the boots, we proceeded to plug in the sensors to the WalkinSense devices in both boots.

Before the general analysis, an experimental trial was performed where all devices were turned on, the Bluetooth connected to the laptop, and real time confirmation was obtained on whether all sensors were operational during the participant's walk. It was also checked that during gait the layout of the insole appeared in the screen showing the position of the sensors according to the arrangement previously determined (Figure 2).

The test was carried out on a flat surface to provide regularity in the data obtained.

### 3. Results and discussion

#### 3.1. Analysis before footwear alteration

For the kinetic analysis, initially a comparison between the left and right foot before the alteration in the boots was intended. However, given that the maximum distance in the lab was limited, the participant was forced to turn around shortly after beginning to walk. This caused breaks in stride length and changes in pressure due to the body's rotation when turning. Therefore, it was decided to include for analysis only 7 steps for each foot.

The plantar distribution on the insole differs greatly from left to right foot (Figure 3). On the scatter graph a continuous line represents the left foot and a dashed line the right. The left foot applies more force in the heel area, while the right foot applies more force on the plantar and metatarsals area. This pattern on the left foot was

expected, given that, due to his pathology, the participant places the heel with too much force and does not apply force in the area of the metatarsals at the end of a step. This is due to the fact that he can hardly move his toes and does not have enough strength to propel himself with this part of the foot (to push off the ground with the big toe), thus leading to an absence of charge transfer between the legs.

This result confirms the results of the evaluation by X-rays, where the ends of the feet seem to denote a certain degree of hypoplasia of the third and fourth metatarsals on the left, and possibly an adducted foot [13]. Therefore, the length of the right step is markedly low due to the lack of strength on the left frontal foot. When the right foot lands on a surface with the heel (the first support is done at the initial contact of the heel to the ground) and does a complete cycle of motion, it applies more force at the metatarsals to compensate for the lack of strength on the front of the left foot during stride. Therefore, since there is more support during the support phase of the right foot (there is a flattening and total contact of the foot), the left foot is projected forward with more force, thus originating a longer step than with the right. Through the 3D image of the sensors in the graph for the left foot, it is evident that only the back of the foot is bearing any load. In the front, only sensor 3 (which is located in the center of the metatarsals) has load, albeit a small one. The right foot shows a plantar pressure distribution in all sensors, although it appears that there is more pressure on the metatarsal area.

The most obvious areas where there is a high asymmetry of plantar pressure distribution between the left and right foot are located in sensor 5 of the left foot and for sensors 1 and 3 of the right foot. This is due to the fact that the all the load on the left foot is virtually in the heel. The two peaks for the same sensor are explained with the fact that the heel does almost all the support phase in the change of foot during walking (charge transfer).

On the right foot, the most marked pressure difference occurs in sensor 3, which is located in the middle of the metatarsals. Sensor 1 shows no load, that is, the left foot carries no load on the metatarsal I, which is located in alignment with the big toe. In contrast, for the right foot more pressure is exerted on sensor 3 (metatarsal II) and sensor 1 (metatarsal), for the reason mentioned above.

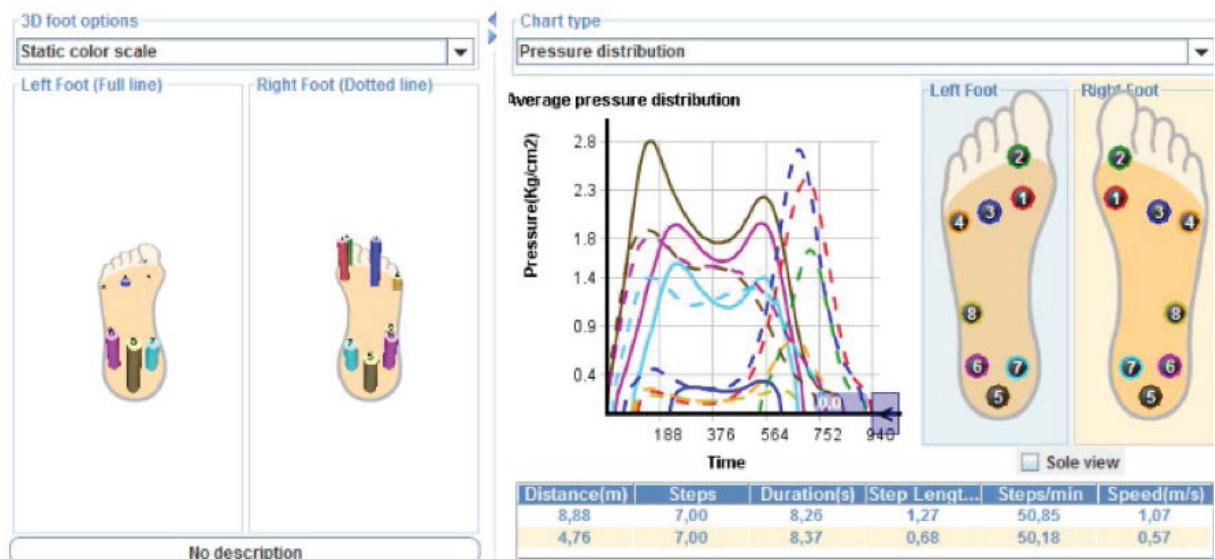


Fig.3.Evaluation of pressure for both feet before footwear alteration (left – continuous line and right – dashed line).

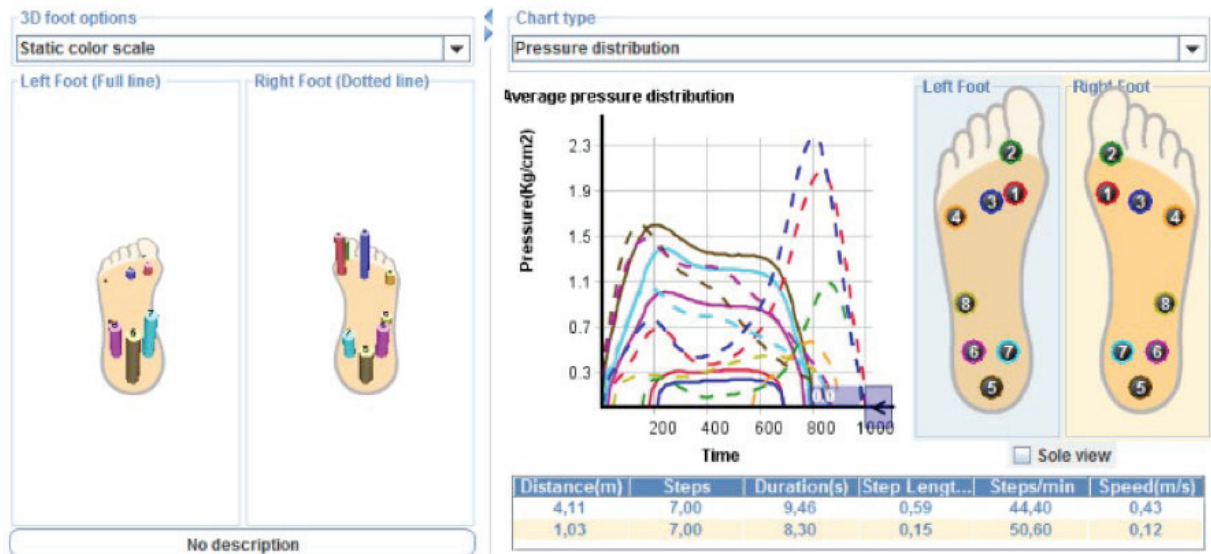


Fig. 4. Evaluation of pressure for both feet after alteration of footwear (left – continuous line and right – dashed line).

### 3.2. Analysis after footwear alteration

The evaluation after altering the boots was carried out using the same procedures. Data allowed for a comparative analysis, initially on the differences between the left and right foot after alteration. Afterwards, a comparison was made between the left foot before and after alteration, with the same procedure for the right foot.

Overall, in comparison with the previous analysis, there were improvements in the gait. The left foot showed less load on the heel (Figure 4), with a decrease from approximately  $2.8\text{kg/cm}^2$  to  $1.6\text{kg/cm}^2$ . The second peak of sensor 5 virtually disappeared, thus approaching the values for the right foot. Sensors 1, 3, and 5 of the right foot also showed a slight decrease in plantar pressure. Sensor 3 went from  $2.7\text{kg/cm}^2$  to  $2.3\text{kg/cm}^2$ , and sensor 1 from  $2.4\text{kg/cm}^2$  to  $2.0\text{kg/cm}^2$ .

This decrease in load for the right foot is due to the fact that the left foot is now capable of taking more load during walking. As for stride length, there is still a marked difference between the left and right foot. Still, step length was shorter for both feet in comparison with the trial before alteration. Since both trials were performed at different times, it is hard to explain differences in stride length and gait speed. Still, visually the participant displayed a more stable gait and his hobble almost disappeared.

During the stance phase and when the heel should begin withdrawing with an elevation of the other foot, the left foot still applies force in the heel area. At this stage the right foot practically no longer makes contact with the heel, but with the plantar area. The first peak was very close to the pressures of the right foot.

Sensor 3 (center of the metatarsal) presents a higher difference in the right foot over the left foot, with approximately  $2.3\text{kg/cm}^2$  pressure, thus showing a slight decrease compared to the evaluation on both feet before alteration, which showed  $2.7\text{kg/cm}^2$  pressure.

Sensor 1 also showed pressure differences – 85.06% higher than the left foot (Figure 5). When comparing both feet before alteration, it can be noticed that there is also a slight decrease: before there was a difference of 100%, that is, this sensor was not even seen, because there was no load at that point. The pressure also decreased on the right foot from  $2.4\text{kg/cm}^2$  to  $2\text{kg/cm}^2$ .

This decrease in pressure for sensors 1 and 3 is justified by the existence of a charge transfer, however slight, from the right to the left foot. The participant's gait was not symmetrical, but there was a slight improvement.



Overall, gait analysis with pressure insoles shows improvements in the distribution of plantar pressure, reducing excessive load in both feet for certain areas of the foot.

In the assessment before the alteration the most obvious points with high asymmetry of distribution of plantar pressure, when comparing the left with the right foot, was in sensor 5 of the left foot, with high pressure. Sensors 1, 2, 4, and 8 showed no pressure. The right foot showed higher pressure in sensors 1 and 3. As already mentioned, this happens due to the participant's pathology, which causes him to walk in a calcaneal prone position with his left foot. This is why there is no pressure in the medial foot and metatarsals, where the stance and swing phase happen. Since the participant does not do it, but instead applies the load on the heel, his right step is shorter and, to counteract it, he applies more pressure to the metatarsal area.

The left foot, after alteration of the boots, shows a load reduction along the heel.

Prior to the alteration two peaks appeared, one at the beginning of the step and one in the middle. In the area of the metatarsal II there is a slightly higher load, and the area of the first metatarsal (which is in the big toe alignment) appears operational, although it has reduced plantar pressure. After modification of the boots and by heightening the sole some correction in posture was possible, together with an insole that cradles the foot, which enabled a suitable adjustment of the foot to the boot. All these factors contribute to making the foot more functional.

The right foot also shows improvements in plantar pressure denoted by the pressure decrease in sensors 1 and 3. This fact is justified by the existence of a load transfer, however slight, of the right foot to the left foot. The gait was not symmetrical, but there was a slight improvement.

There was a decrease in speed between the test before and after the modifications. The causes are unknown, although it is possible that the participant's lack of training with the new footwear played a part, as mentioned above.

The human foot is predisposed to the unalterable performance of various forces at the level of the plantar surface, which sometimes makes their functionality conditioned in such a way that it will eventually allow for the occurrence of changes in the distribution of plantar pressure and the consequent pathologies and plantar deformities [15].

Burns et al. [16] conducted a study to evaluate the effect of *pes cavus* and to relate pain in the foot with pressure. These researchers used pressure platforms full time. Results indicated that individuals with *pes cavus* suffer high levels of pain in the feet, and have high compressive plantar loads in comparison with healthy individuals, which may be due to short duration high pressure or long duration low pressure. It was also found that the area of the feet where more pressure is exerted is in the heel and sole of the foot, with similar peak values. This method proved to be useful for the treatment of painful *pes cavus* [16].

By comparing with this study, the observed data are confirmed: although asymmetry occurs, the left foot shows high pressure in the heel and low pressure in the plantar area. The right foot showed force across the foot but with more focus on the sole, which is why the participant shows lack of load transfer during gait.

#### 4. Conclusions

The pathologies and asymmetries were identified and confirmed. The X-ray identified an asymmetry of approximately 29mm between the lower limbs and possible adducted foot. The anthropometric measurements confirmed this deviation. The modifications to the footwear were designed based on these data.

Corrective changes were implemented in the left boot, with a 20-mm increase in the plantar area and approximately 30mm in the heel area. The modified boots showed a marked improvement anthropometrically. They also corrected posture by raising approximately 30mm on the left foot. Thus, the spinal column tends to restore to its natural position, so that the scoliosis detected by X-ray might not advance and may even disappear.

The kinetic gait analysis showed improvements in the distribution of plantar pressure, with a better transfer load after corrective modifications in footwear, as the peak pressure in the left foot decreased from  $2.8\text{kg/cm}^2$  to  $1.6\text{kg/cm}^2$ . The second peak in that foot showed a marked decrease and reduction of peak plantar pressure on the right foot of  $2.7\text{kg/cm}^2$  to  $2.3\text{kg/cm}^2$ .

The proposed objectives were achieved. After identifying pathologies and asymmetries, the boots were modified according to the specificities identified without changing their original appearance. Moreover, an improvement in gait was found, with improvements in plantar pressure distribution and acceptance of footwear by the user.

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